

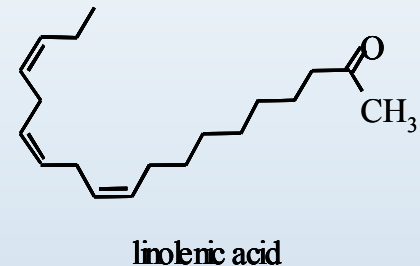
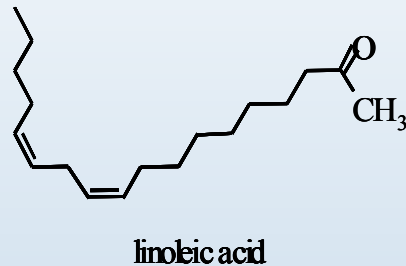
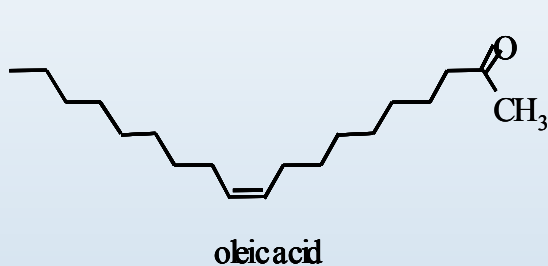
Effects of Biodiesel on Pollutant Emissions

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Clean Cities Informational Webcast on Fuel Blends
March 16, 2005

What is biodiesel?

- Mono-alkyl esters of fatty acids (i.e. methyl or ethyl esters)


$$\begin{array}{ccccccc} \text{100 lb triglyceride} & + & \text{10 lb alcohol} & = & \text{10 lb glycerine (byproduct)} & + & \text{100 lb Mono-alkyl ester} \\ \text{soy oil} & & \text{methanol} & & & & \text{Biodiesel} \end{array}$$

- Must meet the quality requirements of ASTM D6751
- Biodiesel is NOT vegetable oil or used cooking oil
- Vegetable oil and used cooking oil will negatively impact engine durability at blend levels above about 0.5%

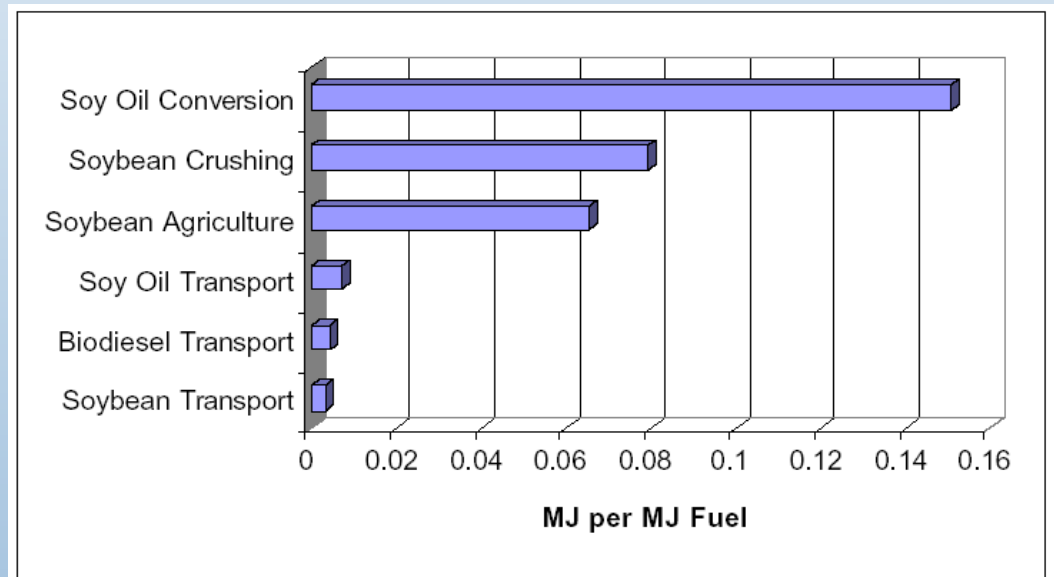
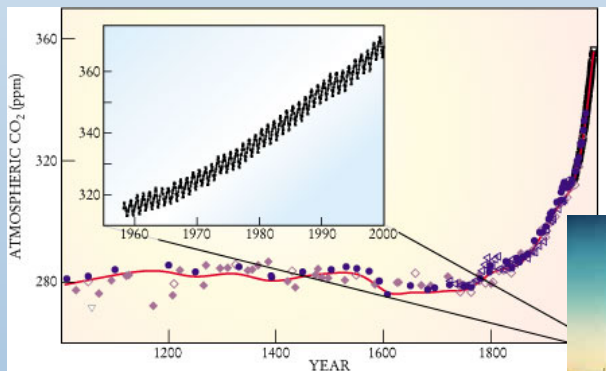
Why Use Biodiesel?

Energy Security and Global Warming Benefits

$$\text{Fossil Energy Ratio (FER)} = \frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$$

For soybean-based biodiesel = 3.2

- *Amount of fossil energy used in biodiesel production is similar to that used in petroleum production*
- *A small fraction of fuel energy-truly renewable*



Biodiesel Warranty Issues

- *Manufacturers warrant their products against defects in materials and workmanship*
- *In general use of a particular fuel should have no effect on the materials and workmanship warranty*
- *Use of biodiesel does not “void the warranty”, this is prohibited by the Magnuson-Moss Warranty Act*
- *Manufacturers are concerned that extensive use of biodiesel will result in increased numbers of warranty claims for what are actually problems caused by the fuel*

Engine and vehicle manufacturers are generally comfortable with blends up to 5%

Concerns about fuel quality and stability are what is preventing approval of blending levels above 5% for most manufacturers

Warranty Statements

While manufacturers do not warrant fuel, many have position statements and recommendations on biodiesel:

| <i>Manufacturer:</i> | <i>Position:</i> |
|-----------------------------|--------------------------------------------------------------------------------|
| EMA | Up to 5% biodiesel, must meet ASTM D6751. |
| Caterpillar | Many engines approved for B100, others limited to B5. Must meet ASTM D6751. |
| Cummins | All engines approved for up to 5% biodiesel, must meet ASTM D6751. |
| Detroit Diesel | Approve up to 20% biodiesel. Must meet DDC specific diesel fuel specification. |
| Ford | Up to 5% biodiesel, must meet both ASTM D6751 and EN 14214. |
| General Motors | All engines approved for up to 5% biodiesel, must meet ASTM D6751. |
| International | Approve up to 20% biodiesel, must meet ASTM D6751. |
| John Deere | All engines approved for 5% biodiesel, must meet ASTM D6751. |

Fuel Injection Equipment:

| | |
|-----------|--------------------------------------------|
| Bosch | Up to 5% biodiesel, must meet EN 14214. |
| Delphi | Up to 5% biodiesel, must meet ASTM D6751. |
| Stanadyne | Up to 20% biodiesel, must meet ASTM D6751. |

What are pollutant emissions?

Regulated pollutants:

Carbon monoxide (**CO**) – a poison

Hydrocarbons (**HC**) – causes formation of ozone

Nitrogen oxides (**NO_x**) – causes formation of ozone and fine particles

Particulate matter (**PM**) – soot and aerosols

For diesel, only PM and NO_x are really important because diesel vehicles contribute only a small fraction of the CO and HC in the air (most comes from gasoline cars)

Unregulated pollutants:

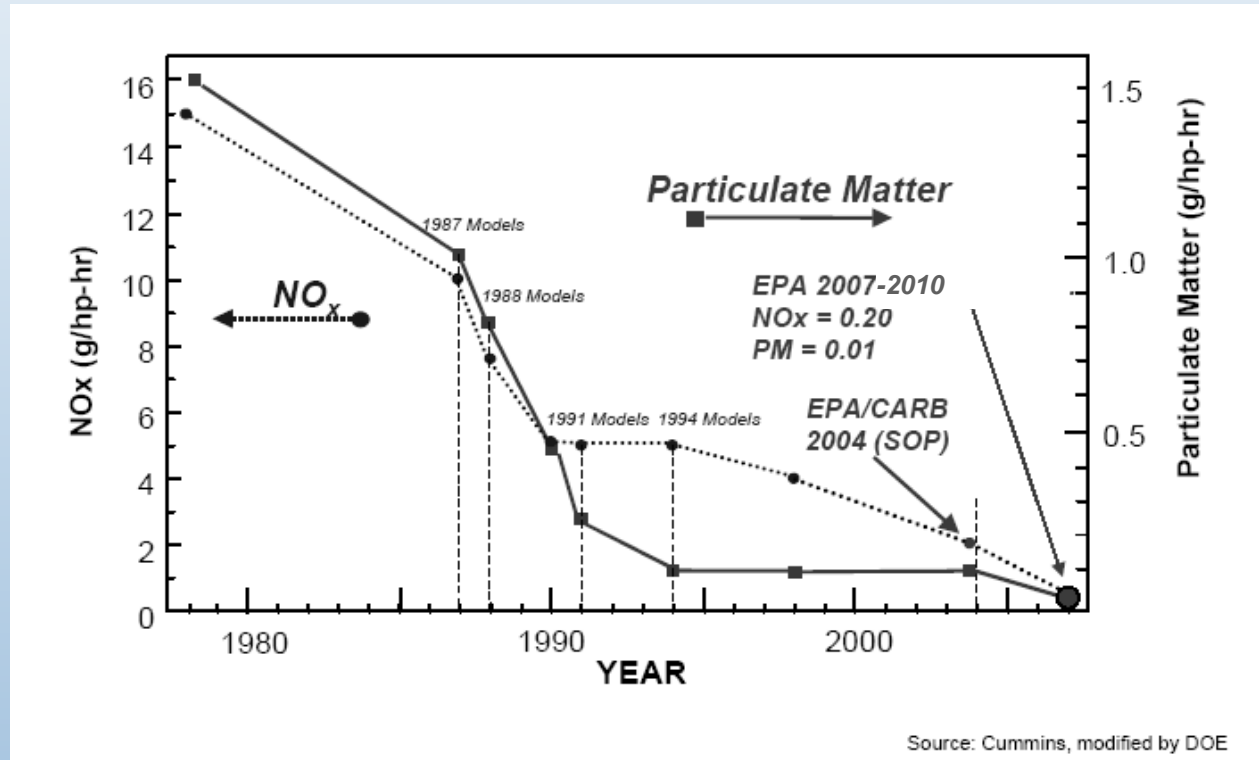
Polyaromatic hydrocarbons (**PAH**) – known carcinogens

Nitro-PAH – known carcinogens

Aldehydes – highly reactive for ozone, have health effects

How are diesel emissions regulated?

- EPA has dramatically lowered allowable levels of PM and NO_x since the 1980s (standards for CO and HC have not changed)
- Beginning in 2007 emission levels will again be dramatically lowered



How are diesel emissions controlled?

Prior to 2002 engine manufacturers used:

- fuel injection timing retard to reduce NO_x
- increased injection pressure (better fuel atomization and mixing) to reduce PM

Beginning in 2002 exhaust gas recirculation has been used to further reduce NO_x

In 2007 manufacturers will use particle filters to reduce PM emissions by more than 90% - requires ULSD (15 ppm sulfur)

Between 2007 and 2010 catalyst systems that reduce NO_x emissions will be phased in – requires ULSD (15 ppm sulfur)

How are engines tested to insure compliance?

Engines are tested on an engine dynamometer over a range of speeds and loads (transient tests) as well as at several steady state conditions

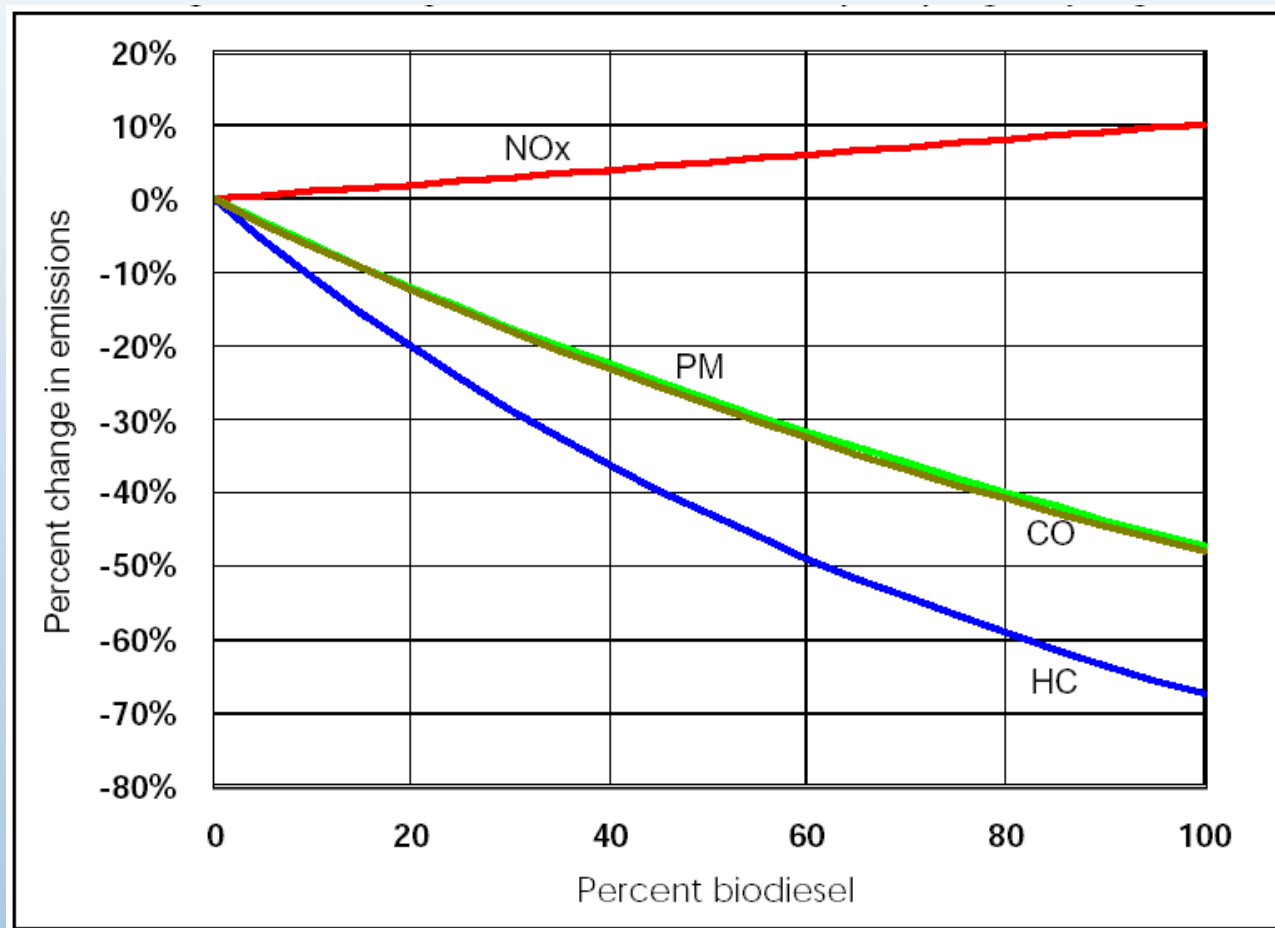
Emissions of regulated pollutants are reported in g/bhp-h (or weight per unit of work done by the engine)



Biodiesel's Effect on Emissions – Older Engines

EPA analysis:

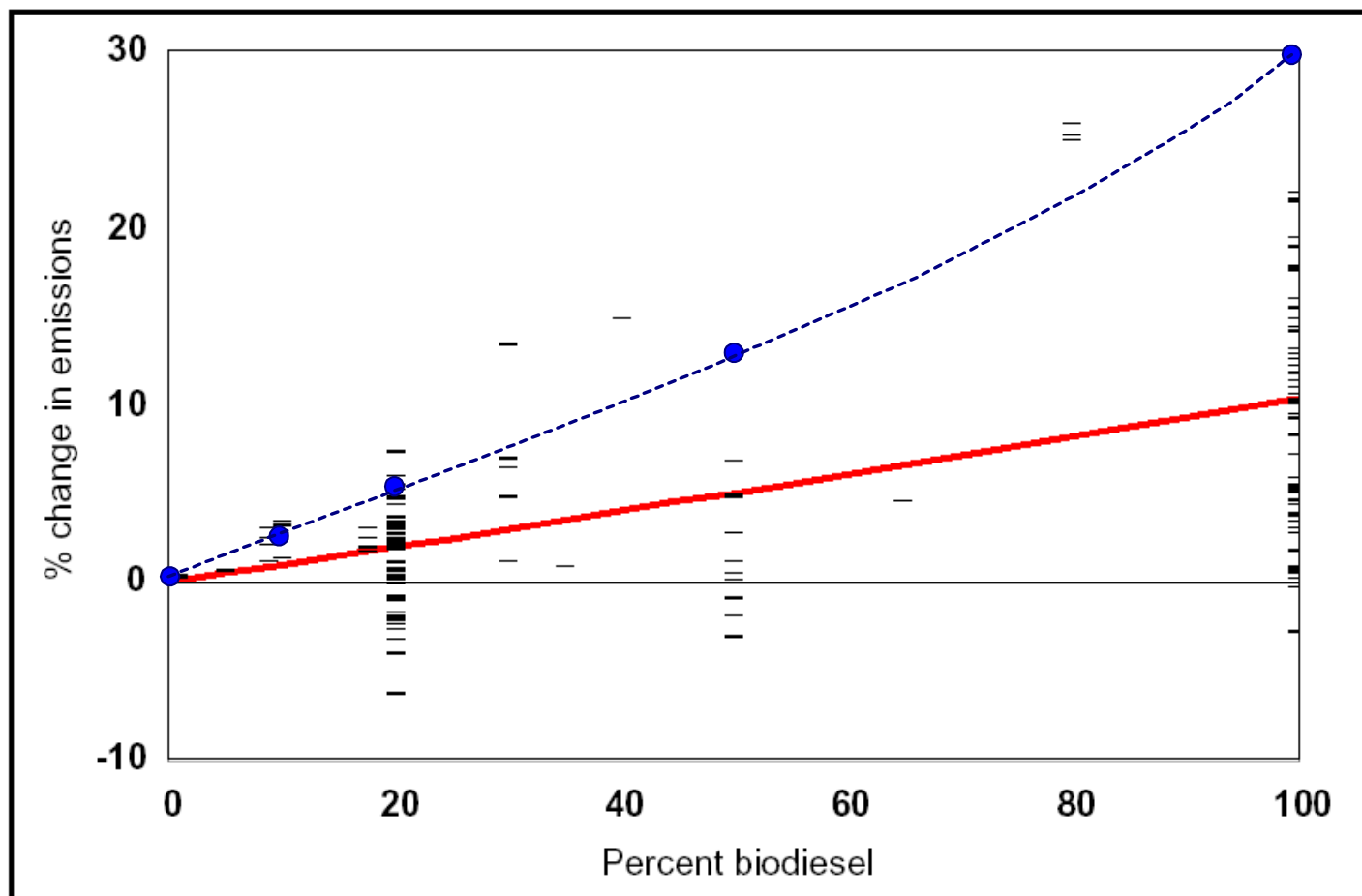
- data from many studies
- engine models through 1997
- NO_x
 - No change for B5
 - 2% up for B20
 - 10% up for B100
- PM
 - 5% down for B5
 - 12% down for B20
 - 48% down for B100



Biodiesel's Effect on NOx Emissions

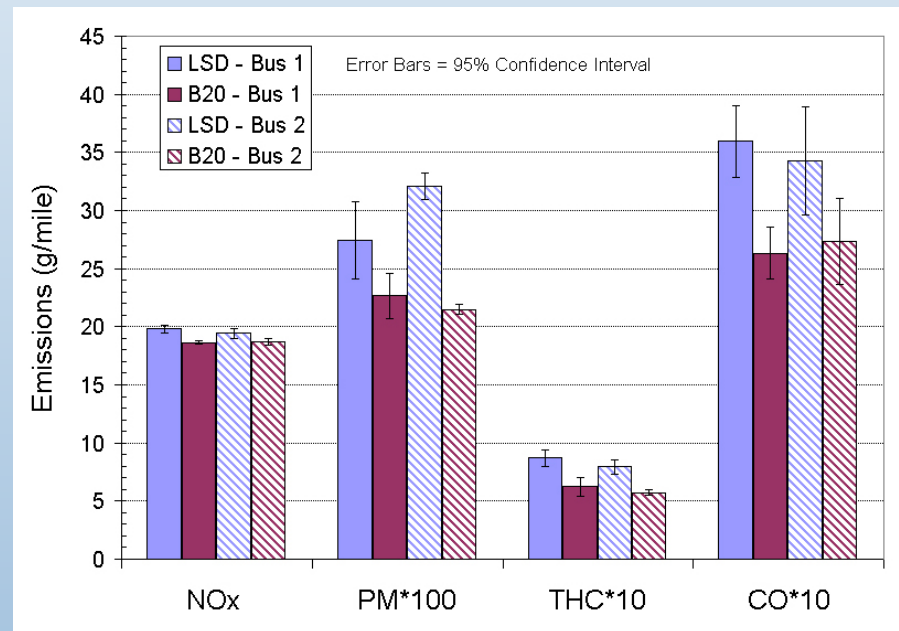
Typical Older Engines (thru 1997): B20 = +2%, B100 = +10%

Newer Engines (2004 compliant): B20 = +4%, B100 = +30%



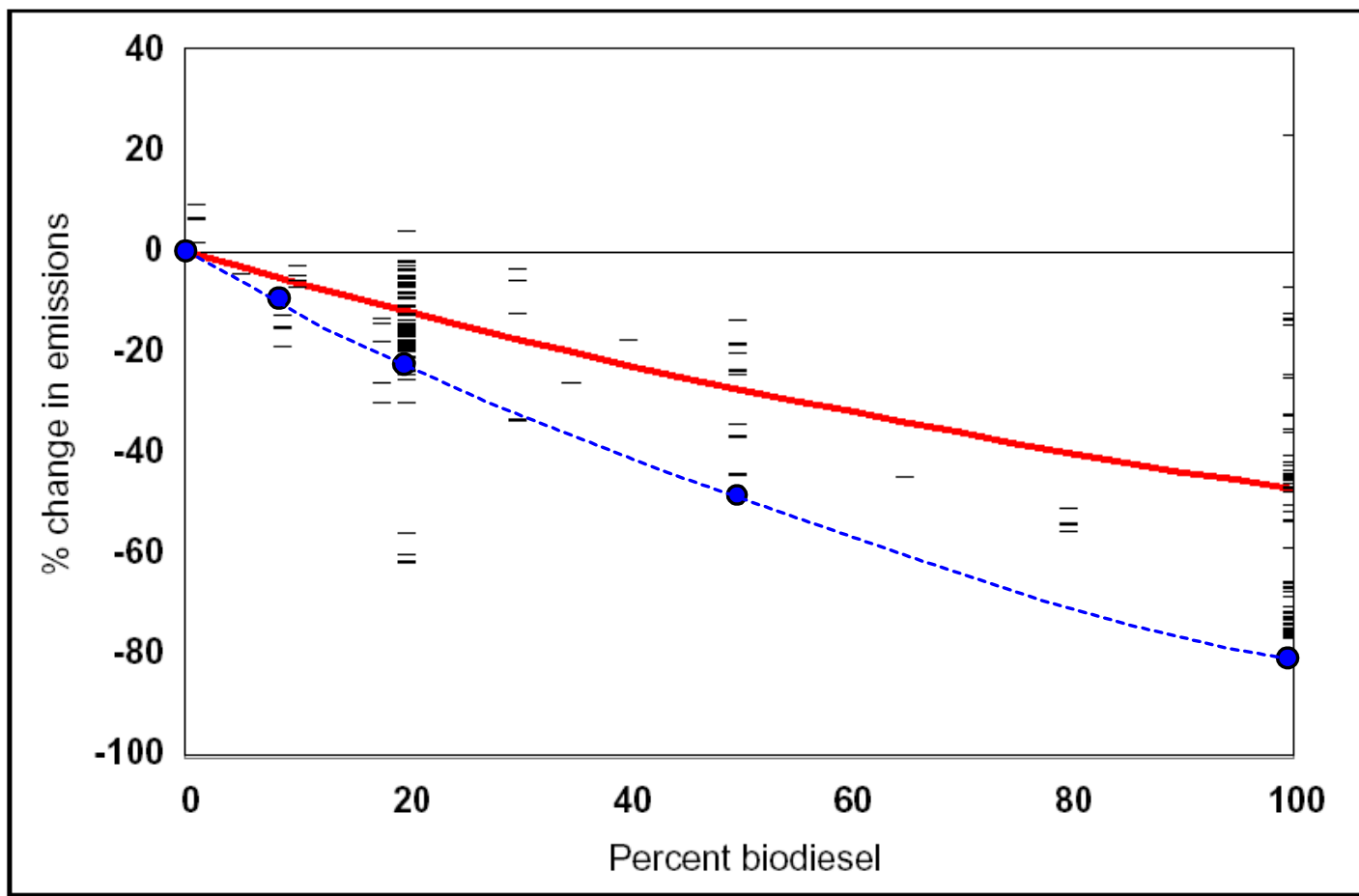
Biodiesel Bus Chassis Dynamometer Testing

- B20 vs. conventional diesel fuel
- 2 in-use buses tested
- City Suburban Heavy Vehicle Cycle (CSHVC)
- Cummins ISM 2000 Engine – No EGR
- Expected reductions (g/mile basis)
 - PM \approx 24%
 - HC \approx 40%
 - CO \approx 32%
 - Fuel Economy \approx -3%
- Unexpected reductions in NOx
 - 5% reduction
 - statistical confidence > 99%

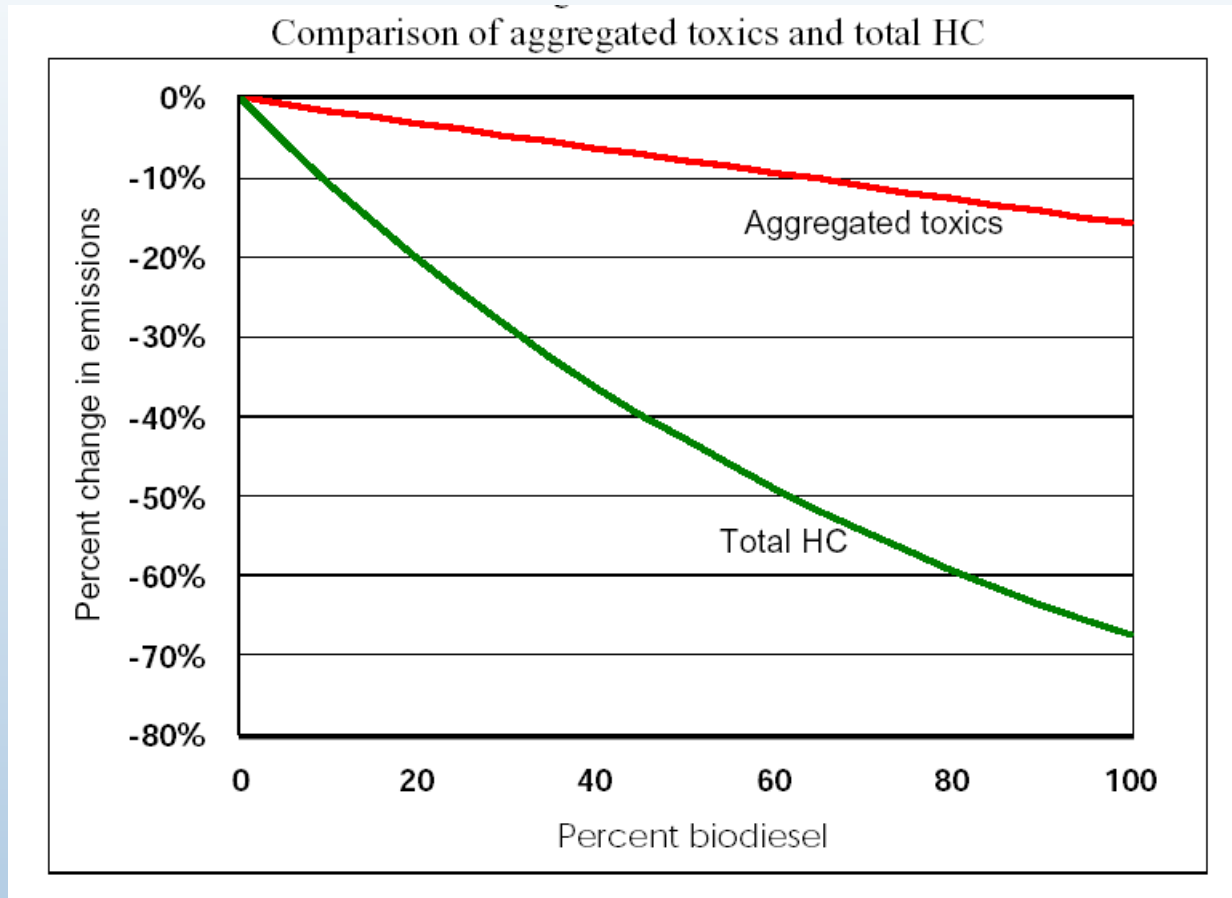


Biodiesel's Effect on PM Emissions

Typical Older Engines (thru 1997): B20 = -10%, B100 = -45%
Newer Engines (2004 compliant): B20 = -25%, B100 = -75%



Gaseous Toxics Emissions



Significantly lower for biodiesel

Closing Remarks

- The real advantages for use of biodiesel are in reducing petroleum consumption and greenhouse gas emissions
 - These advantages are independent of blend level and are proportional to the amount of B100 consumed
- Use of biodiesel blends can significantly reduce PM and toxic compound emissions, but may slightly increase NO_x
- Most manufacturers currently are supportive of blend levels up to 5%
 - Many require the biodiesel meet ASTM D6751
 - Some have additional requirements on biodiesel quality

<http://www.nrel.gov/vehiclesandfuels/npbf/publications.html>

